Spectroscopic Databases and Manifold Learning for Surveys of the 2020s

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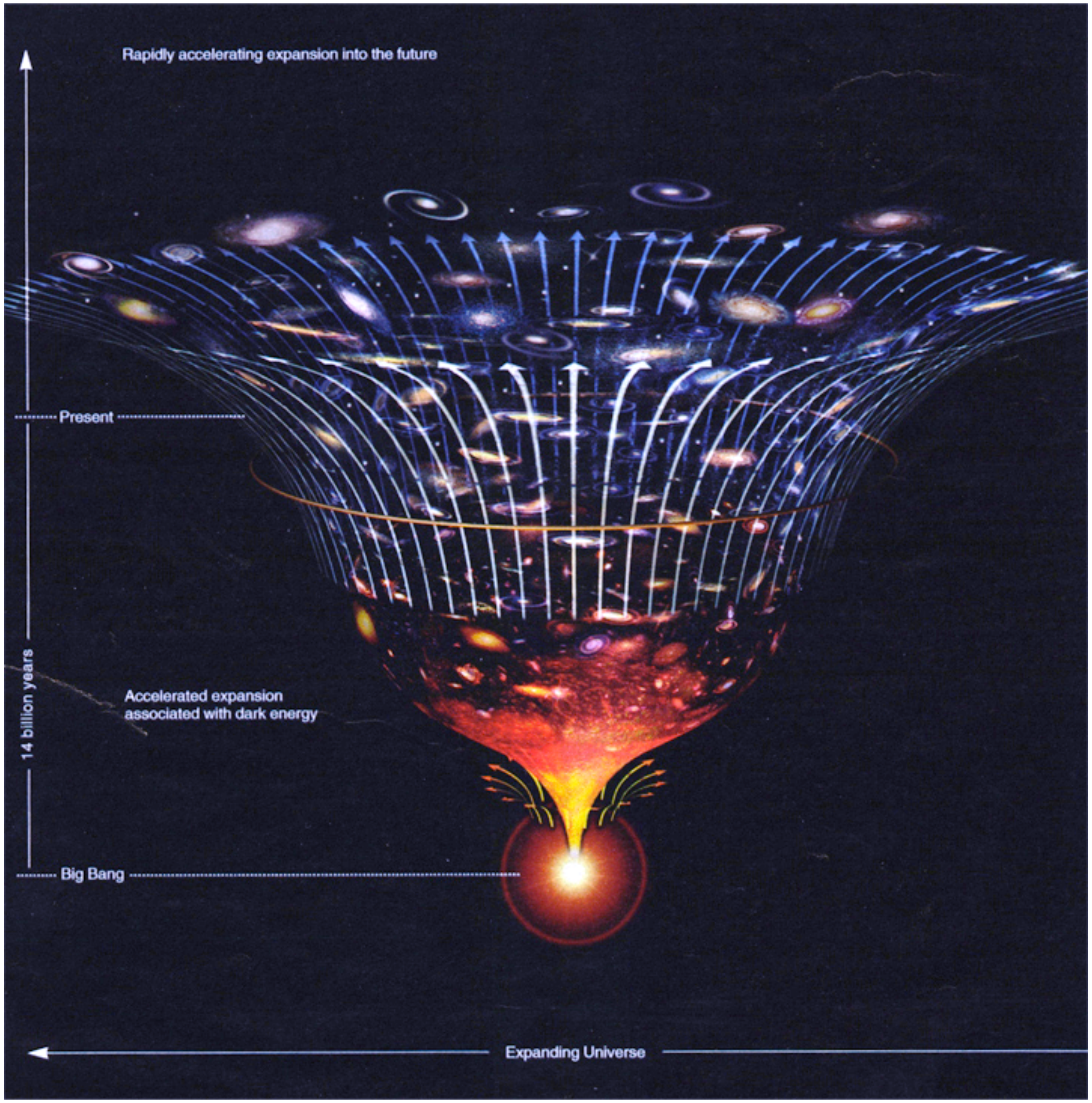


Breakthrough from the 1990s:
Accelerating cosmic expansion

2011 Nobel Prize in Physics

Λ?

The Redshift Measurement Problem

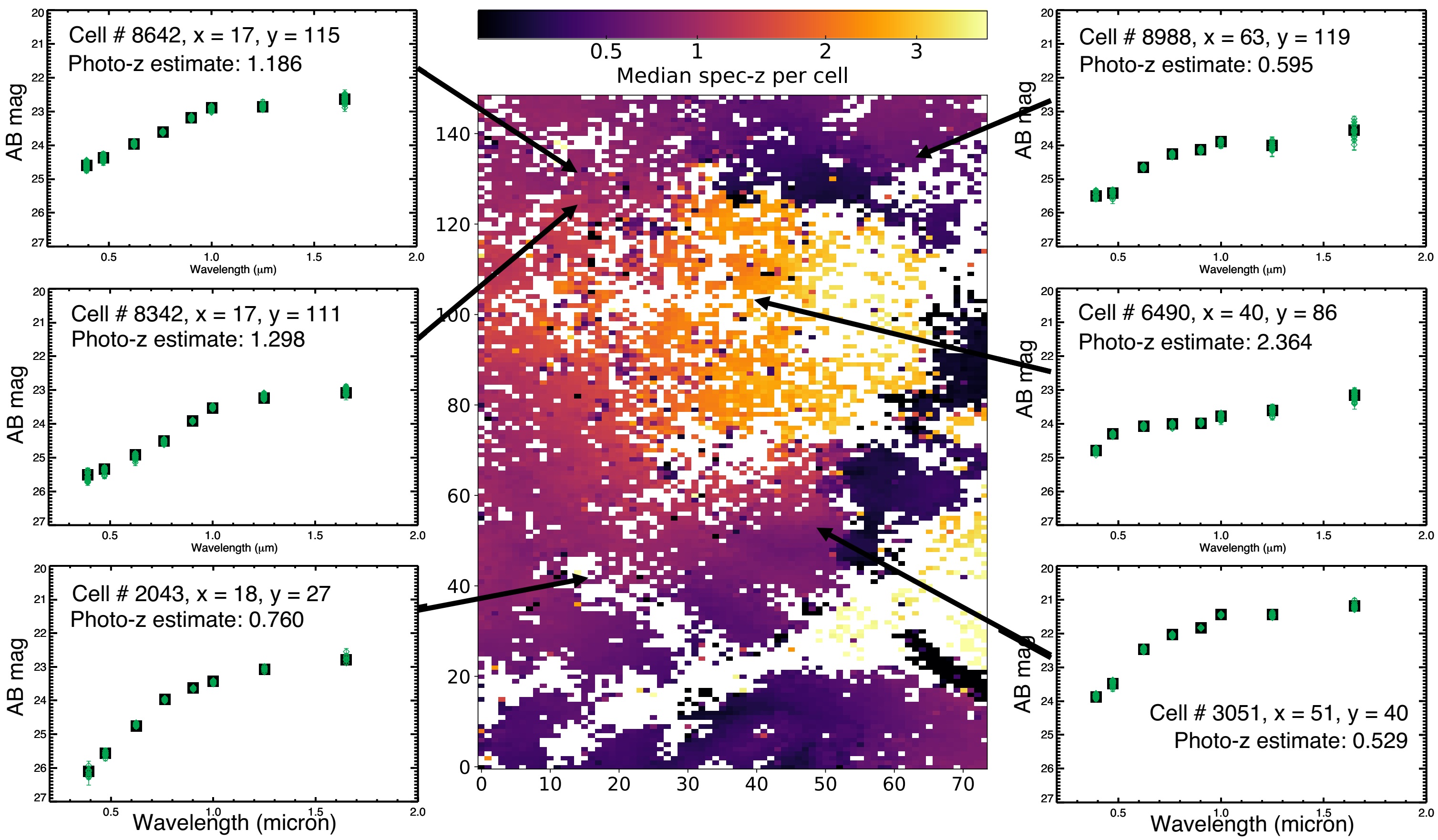
- Billions of galaxies will be imaged by the Stage IV cosmology surveys (LSST, Euclid, WFIRST)
- Only possible to get spectroscopic redshifts for a small fraction
- Weak lensing cosmology requires that the redshift distributions of galaxies in ~10-20 redshifts bins be known with **high accuracy**

→**Photometric redshifts will necessarily be crucial for weak lensing cosmology missions**

Manifold learning / nonlinear dimensionality reduction (NLDR)

- Group of techniques to characterize / explore high-dimensional data and correlations in high dimensions
- Common ones includes the self-organizing map (SOM), t-SNE, local linear embedding (LLE), and UMap
- Most project the high-D manifold down to a lower-D representation
- Whereas deep convolution networks try to learn a complex high-dimensional relationship between input data and output labels, NLDR just tries to unwrap the high-D data in an unsupervised way – no outputs

Self-organized map of galaxy colors to Euclid depth



Masters et al. 2015, ApJ, 813, 53

The galaxy color manifold

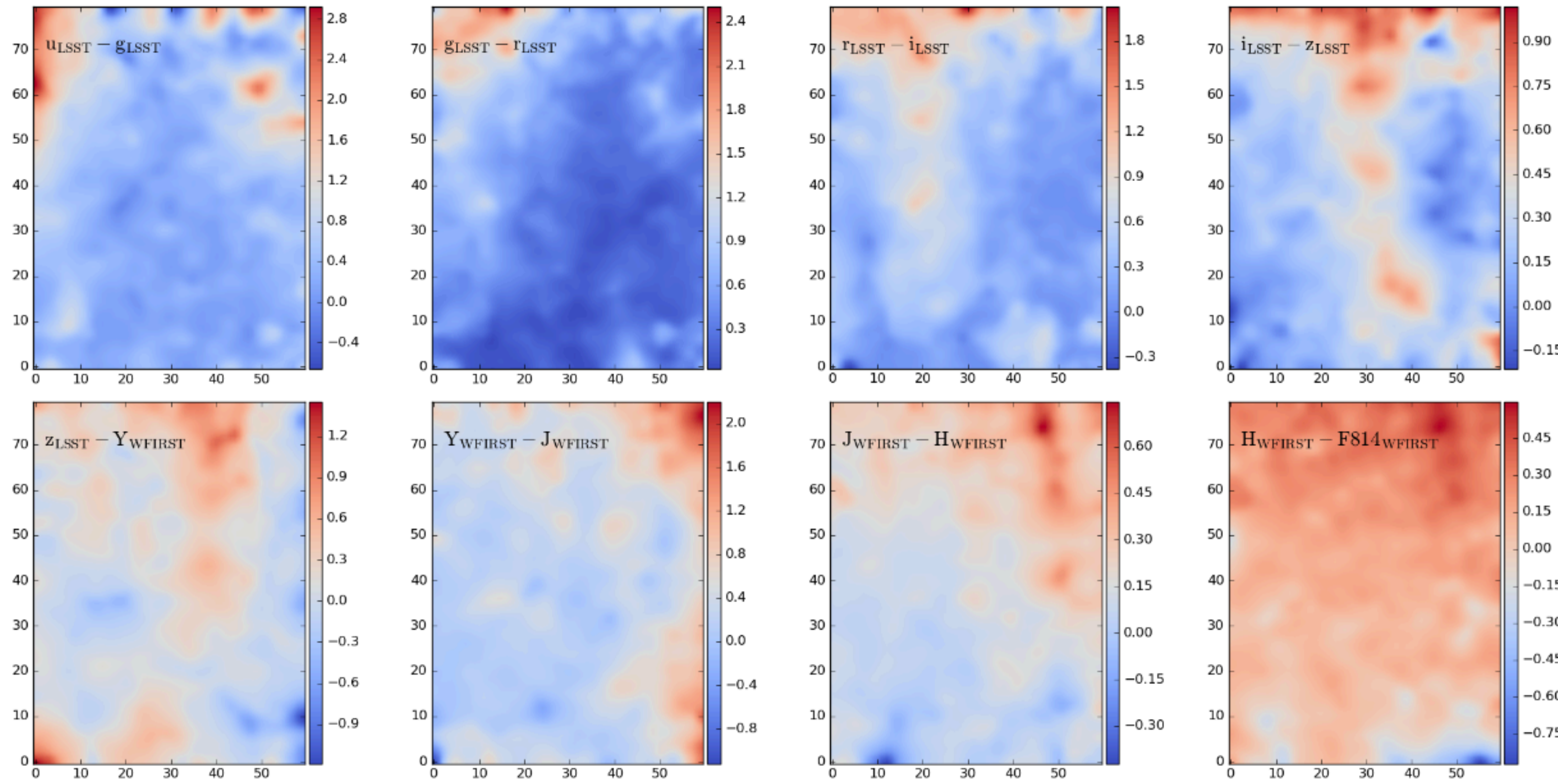
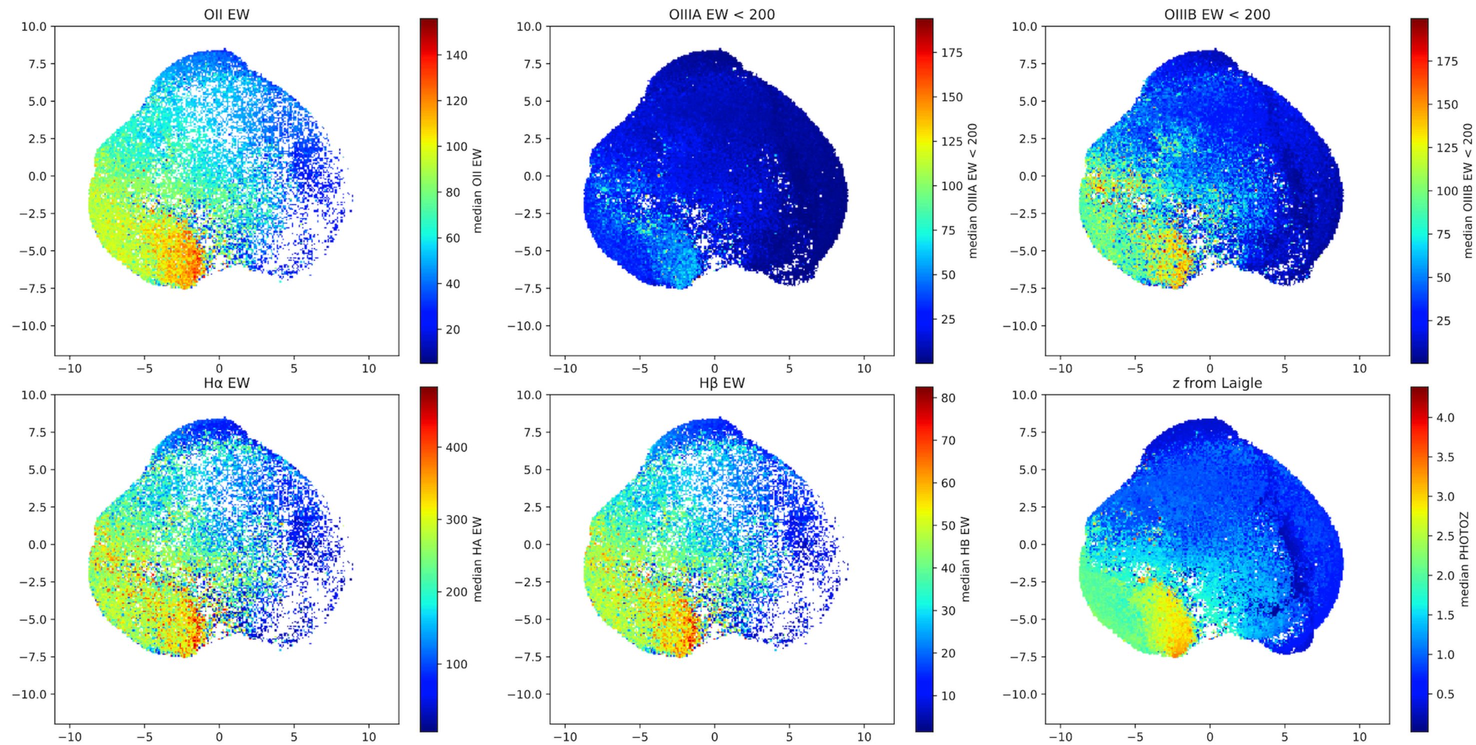


Figure 5. LSST and *WFIRST* colors of the trained SOM at each cell from top-left to bottom-right color-coded by: $\mathrm{u_{LSST} - g_{LSST}}$, $\mathrm{g_{LSST} - r_{LSST}}$, $\mathrm{r_{LSST} - i_{LSST}}$, $\mathrm{i_{LSST} - z_{LSST}}$, $\mathrm{z_{LSST} - y_{WFIRST}}$, $\mathrm{y_{WFIRST} - j_{WFIRST}}$, $\mathrm{j_{WFIRST} - H_{WFIRST}}$, and $\mathrm{H_{WFIRST} - F184W_{WFIRST}}$. SOM is selected to be a mesh of 80×60 cells. The axes are arbitrary and each position on the two dimensional map points to a position in the 8 dimensional color space.

Hemmati et al. 2018

Other techniques – UMap



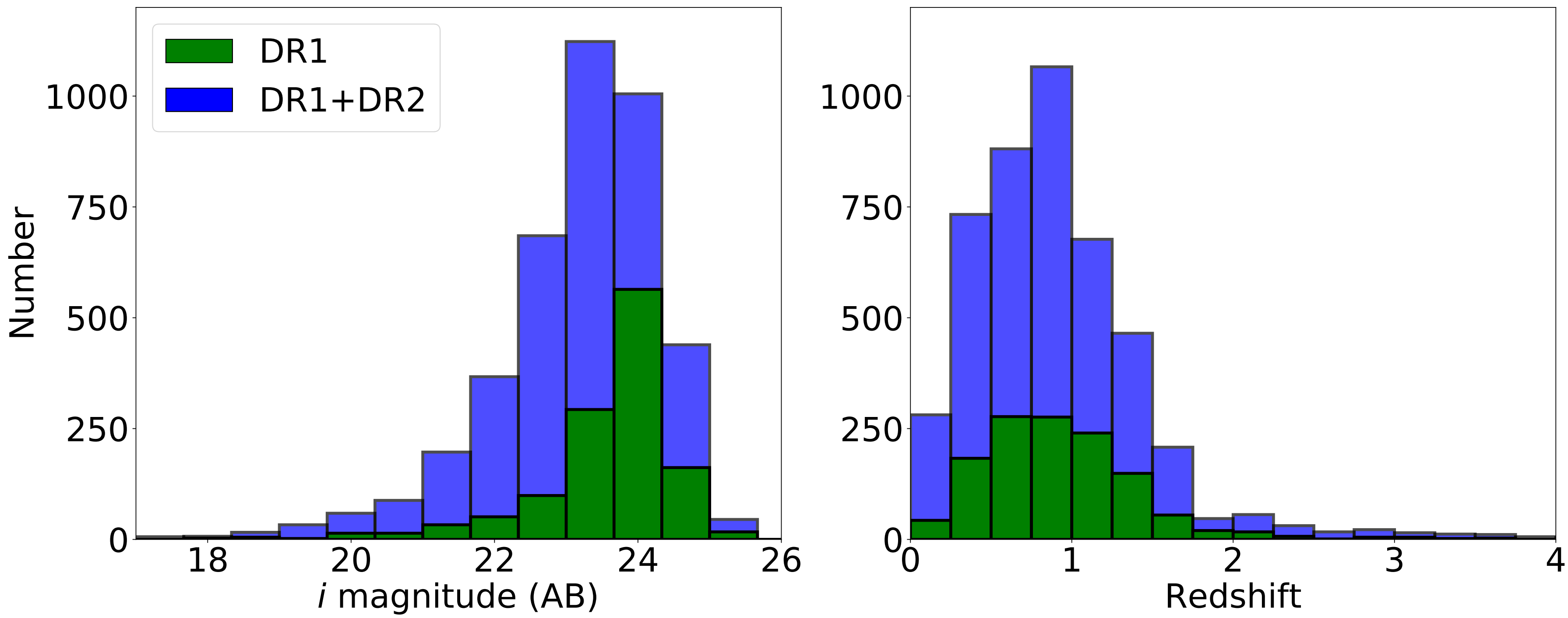
C3R2 = Complete Calibration of the Color-Redshift Relation

Judith Cohen (Caltech) - PI of Caltech Keck C3R2 allocation
16 nights (DEIMOS + LRIS + MOSFIRE, kicked off program in 2016A)
Daniel Stern (JPL) - PI of NASA Keck C3R2 allocation
10 nights (all DEIMOS; "Key Strategic Mission Support")
Daniel Masters (JPL) – PI of NASA Keck C3R2 allocation 2018A/B. **Observed last night, and will again tonight**
10 nights (5 each LRIS/MOSFIRE; "Key Strategic Mission Support")
Dave Sanders (IfA) - PI of Univ. of Hawaii Keck C3R2 allocation
6 nights (all DEIMOS) + H20
Bahram Mobasher (UC-Riverside) - PI of UC Keck C3R2 allocation
2.5 nights (all DEIMOS)

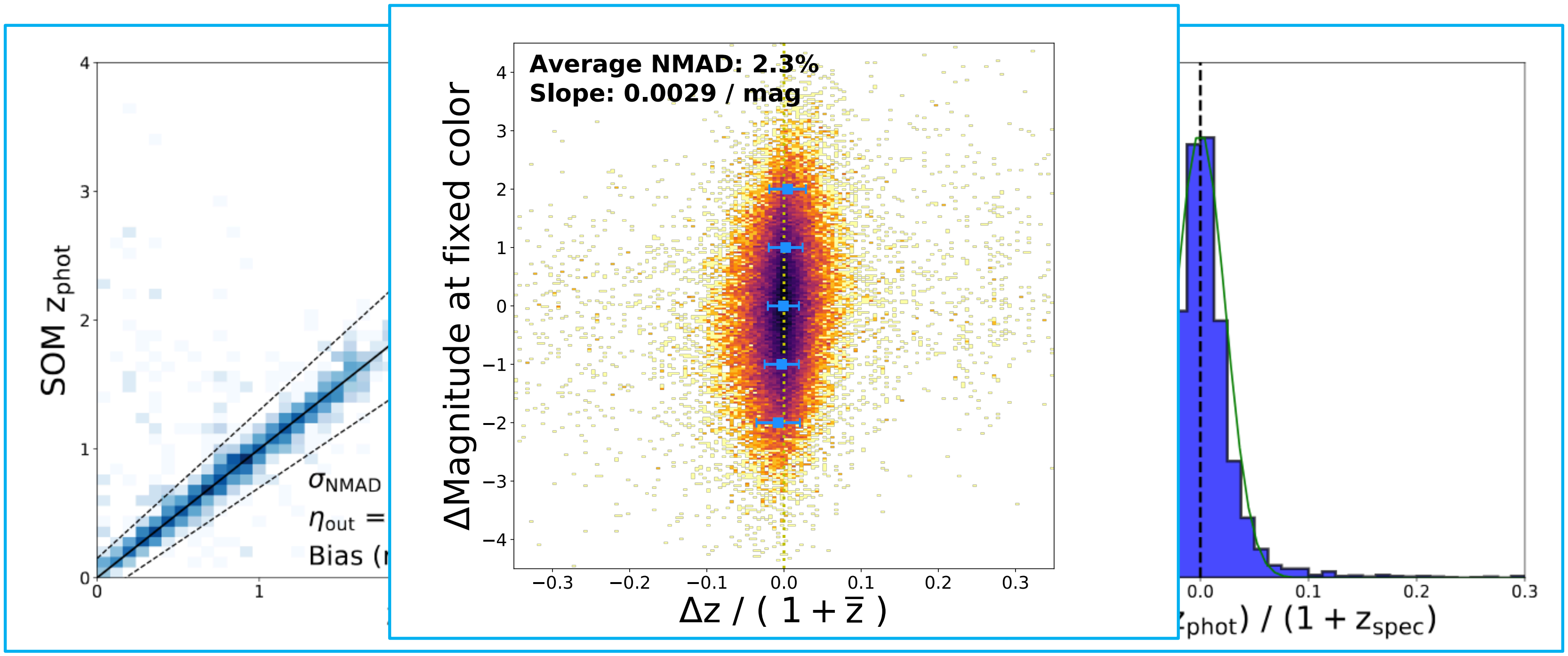
+ time allocations on VLT (PI F. Castander), MMT (PI D. Eisenstein), and GTC (PI C. Guitierrez)
-Sample drawn from 6 fields totaling ~6 deg^2

Additional Collaborators: Peter Capak, S. Adam Stanford, Nina Hernitschek, Francisco Castander, Sotiria Fotopoulou, Audrey Galametz, Iary Davidzon, Stephane Paltani, Jason Rhodes, Alessandro Rettura, Istvan Szapudi, and the Euclid Organization Unit – Photometric Redshifts (OU-PHZ) team

C3R2-Keck stats through DR2 (2016A-2017A)



C3R2 – Results from SOM method

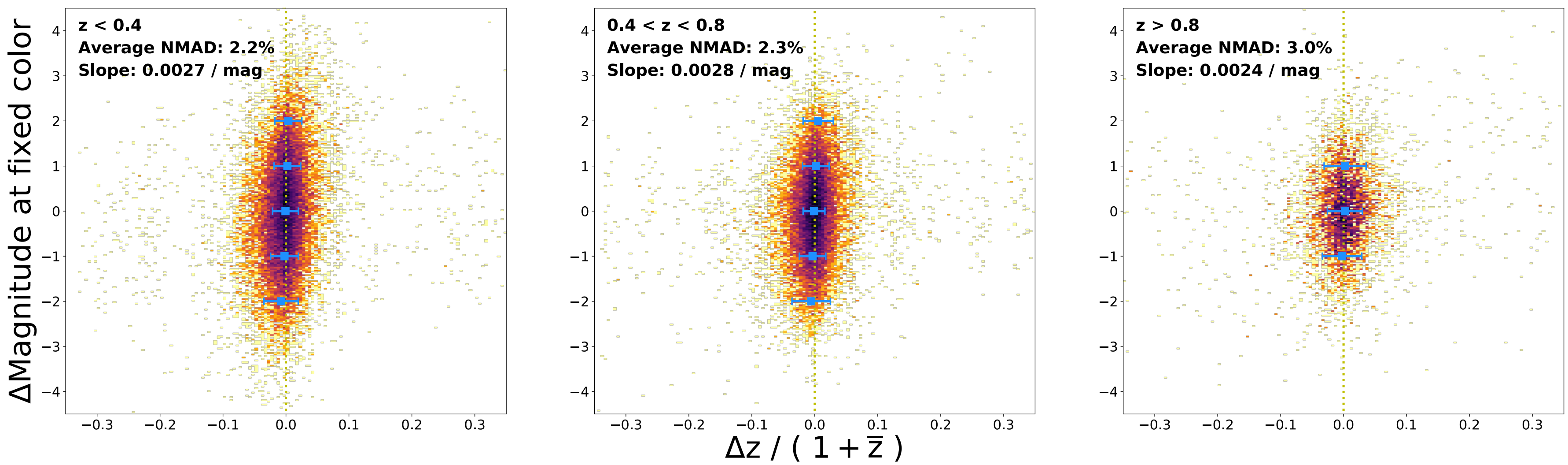


- Compare spec-zs of unique pairs of galaxies at fixed color (SOM position)
- Illustrates weak (and measurable) secondary dependence of redshift on magnitude *at fixed color* in the LSST+Euclid color space

Outlier fraction 4.1%, scatter 2.3%, bias of -0.2%

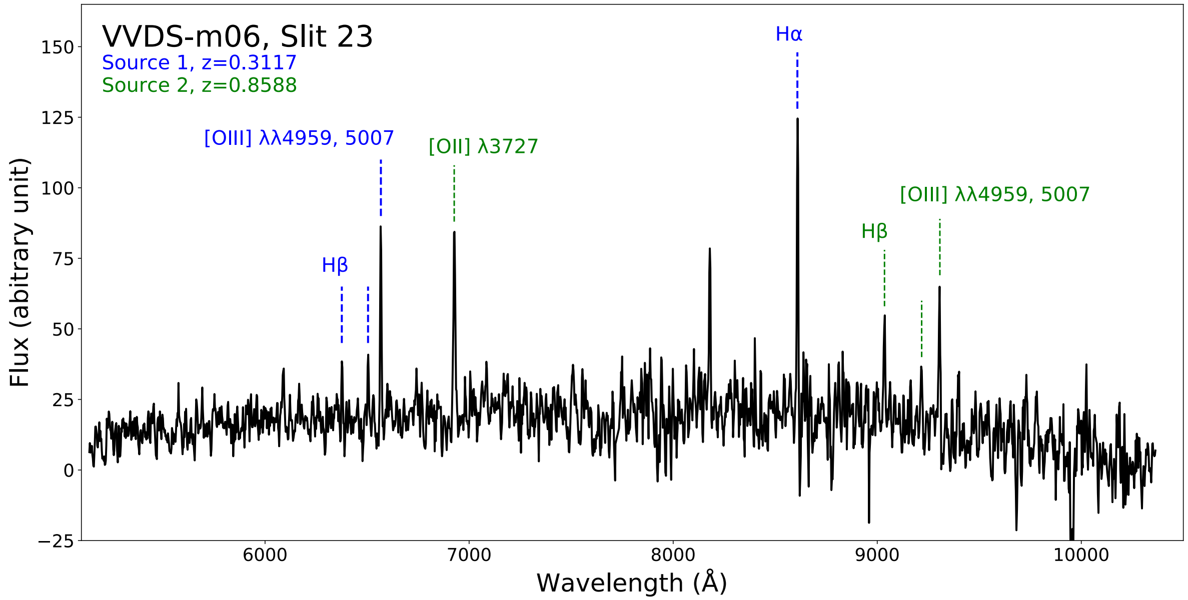
→ Method achieving unbiased performance

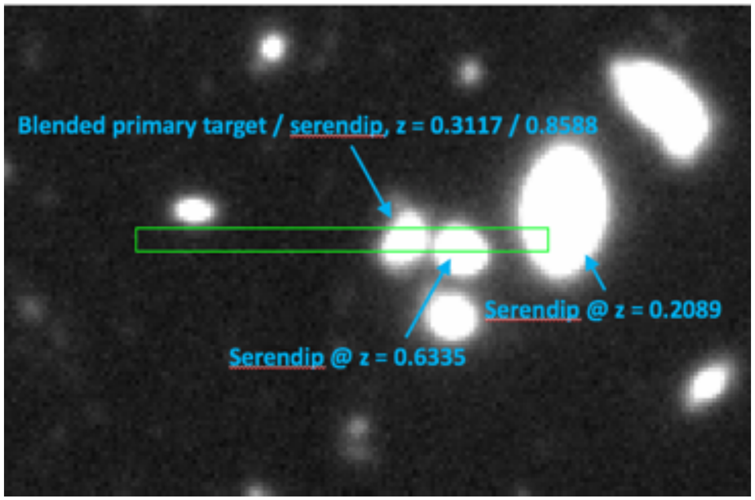
Remarkably stable relationship of dmag/dz at fixed color



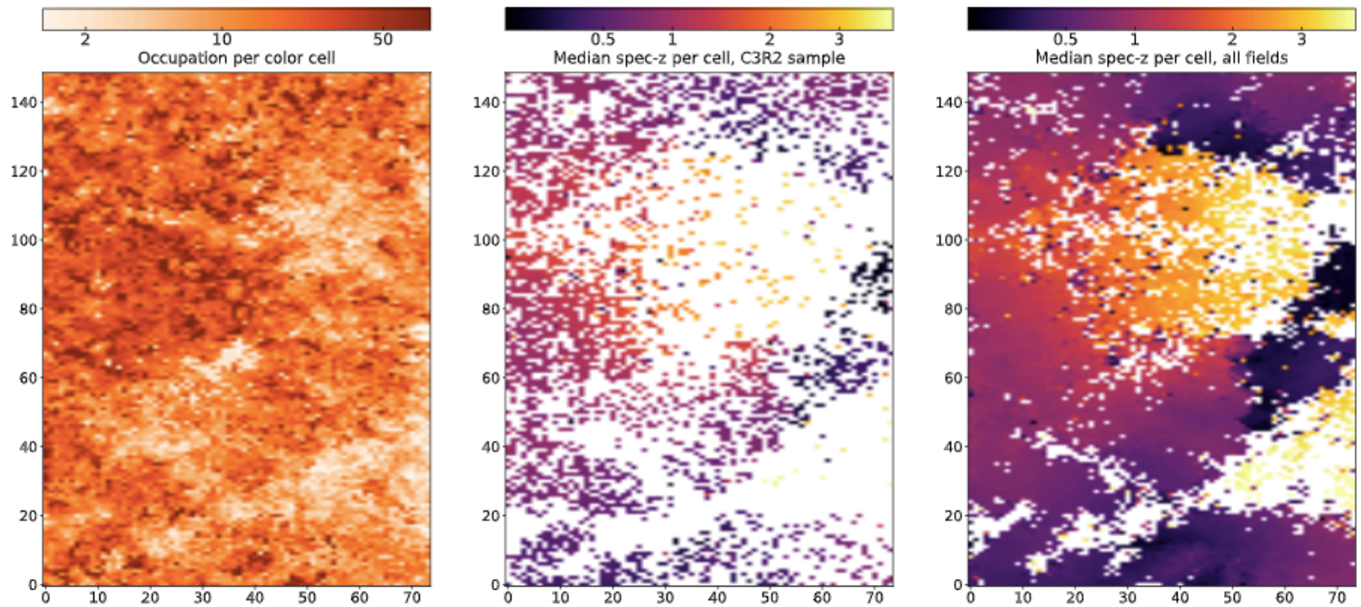
Hemmati et al. 2018

Ambiguous redshifts





Color coverage to Euclid depth



- Much of the galaxy color space explored to significant depth (>75% of cells; >85% of galaxies in cell with at least 1 specz, many cells with >>1 specz); some cells remain uncalibrated at present.
- C3R2-Keck alone covering >35% of the color space

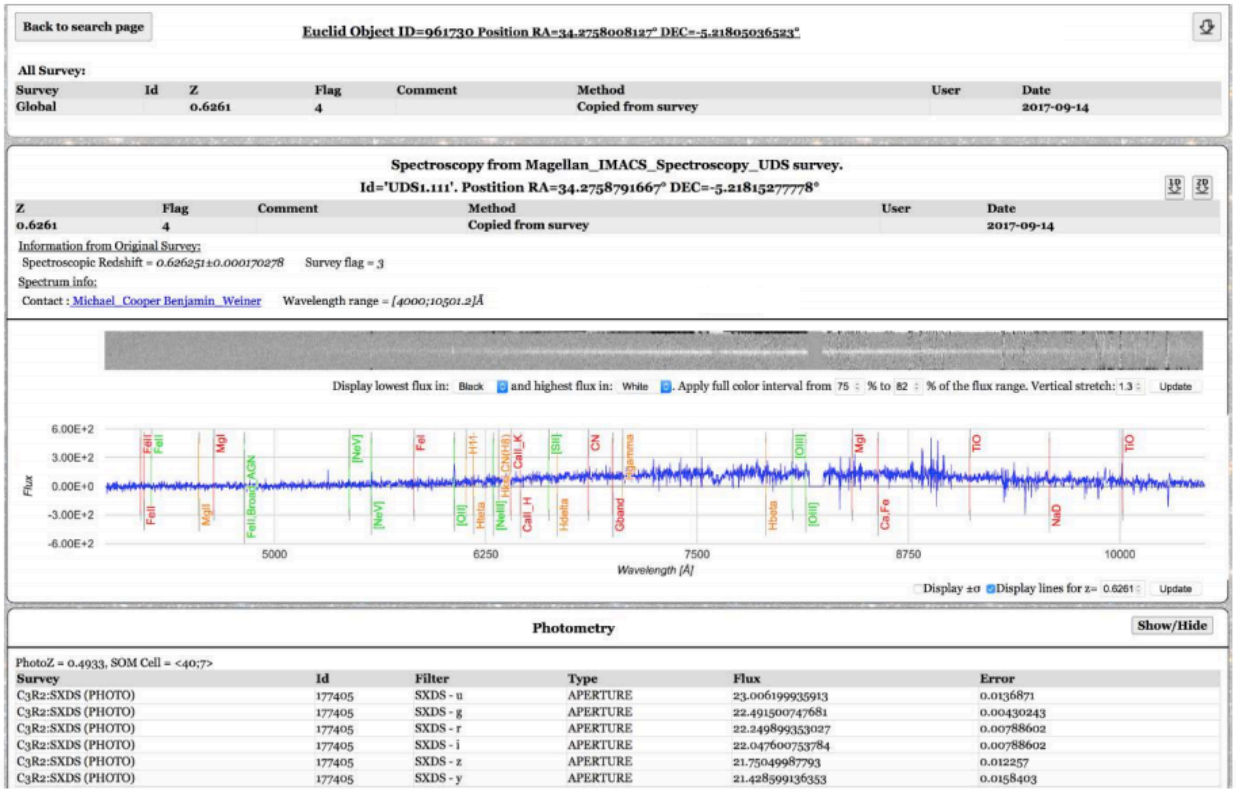
Spectroscopic Databases – challenges

- We will have hundreds of thousands of deep galaxy spectra in the 2020s, growing continuously
- Need a database that can easily ingest new spectroscopy from disparate sources (e.g., from grisms)
- Extremely careful vetting of spec-zs necessary for cosmology
- Machine learning-based redshifts may prove critical

All large cosmology surveys would benefit from a single high-quality database of all deep spectroscopy!

A start for Euclid in Geneva

The database – Case example / Read-only



Back to search page

Euclid Object ID=961730 Position RA=34.2758008127° DEC=-5.21805036523°

All Survey:

Survey	Id	Z	Flag	Comment	Method	User	Date
Global		0.6261	4		Copied from survey		2017-09-14

Spectroscopy from Magellan_IMACS_Spectroscopy_UDS survey.
Id='UDS1.111'. Postition RA=34.2758791667° DEC=-5.21815277778°

Z	Flag	Comment	Method	User	Date
0.6261	4		Copied from survey		2017-09-14

Information from Original Survey:
Spectroscopic Redshift = *0.626251±0.000170278* Survey flag = *3*
Spectrum info:
Contact : Michael_Cooper Benjamin_Weiner Wavelength range = *[4000;10501.2]Å*

Display lowest flux in: Black and highest flux in: White. Apply full color interval from 75 % to 82 % of the flux range. Vertical stretch: 1.3 Update

Display ±σ Display lines for z= 0.6261 Update

Photometry Show/Hide

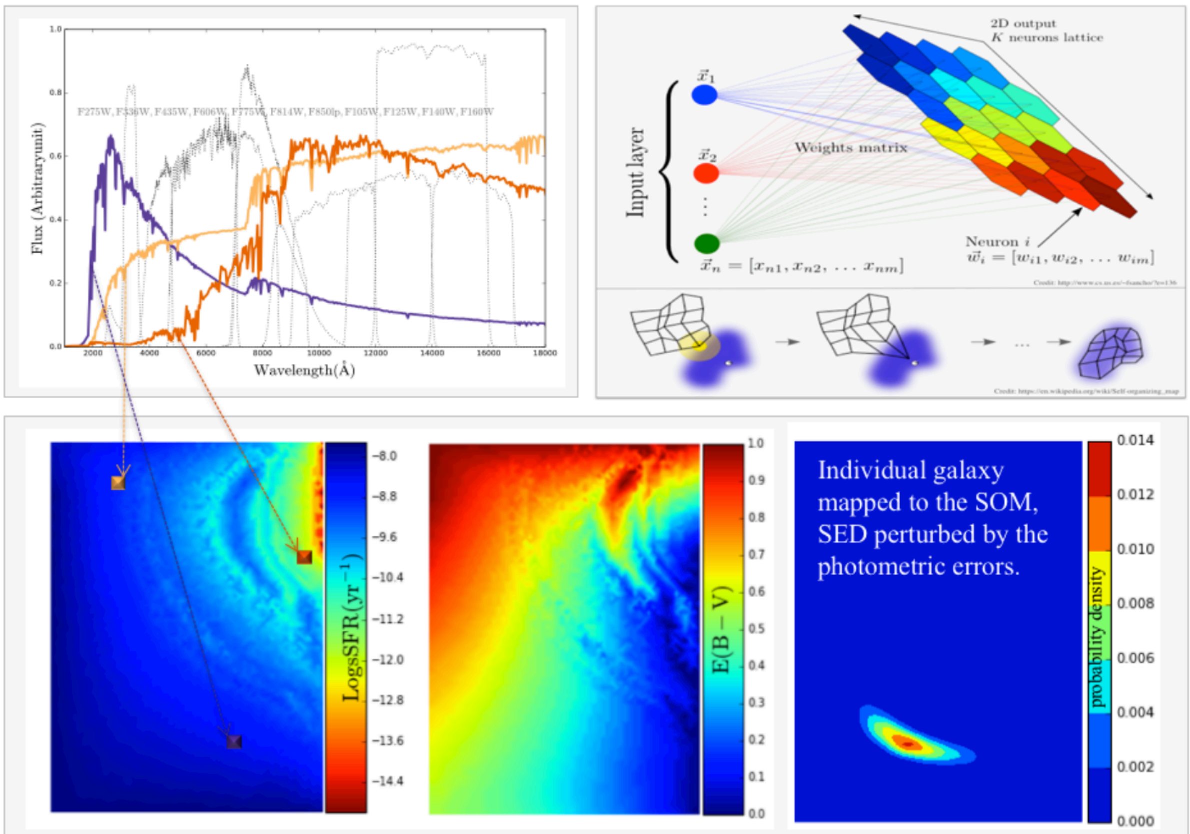
PhotoZ = 0.4933, SOM Cell = <40;7>

Survey	Id	Filter	Type	Flux	Error
C3R2:SXDS (PHOTO)	177405	SXDS - u	APERTURE	23.006199935913	0.0136871
C3R2:SXDS (PHOTO)	177405	SXDS - g	APERTURE	22.491500747681	0.00430243
C3R2:SXDS (PHOTO)	177405	SXDS - r	APERTURE	22.249899353027	0.00788602
C3R2:SXDS (PHOTO)	177405	SXDS - i	APERTURE	22.047600753784	0.00788602
C3R2:SXDS (PHOTO)	177405	SXDS - z	APERTURE	21.75049987793	0.012257
C3R2:SXDS (PHOTO)	177405	SXDS - y	APERTURE	21.428599136353	0.0158403

Galaxies are not unique

- The manifold of galaxy observables is finite, and large surveys like Euclid/WFIRST/LSST will measure essentially the same galaxy over and over
- We can measure the galaxy manifold really well with large surveys.
- Continuity constraints could then allow us to build a dynamic picture of galaxy growth
  - Individual galaxies can be thought of as moving along the manifold.
- What could we learn from this?

Models – can we match them to the data?



Measure the high-dimensional manifold. Then what?

- We have a well-defined target for simulations
- What if we find (as is common) that the simulations produce unphysical galaxies, or can't produce certain real galaxies?
- Is there a way to systematically search for the simulation parameters that produce the observed universe?
- What have we learned about galaxies at the end?
- How do we achieve the "Standard Model"?